Mixed Reality Technology Capabilities for Combat-Casualty Handoff Training

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Abstract. Patient handoffs are a common, yet frequently error prone occurrence, particularly in complex or challenging battlefield situations. Specific protocols exist to help simplify and reinforce conveying of necessary information during a combat-casualty handoff, and training can both reinforce correct behavior and protocol usage while providing relatively safe initial exposure to many of the complexities and variabilities of real handoff situations, before a patient's life is at stake. Here we discuss a variety of mixed reality capabilities and training contexts that can manipulate many of these handoff complexities in a controlled manner. We finally discuss some future human-subject user study design considerations, including aspects of handoff training, evaluation or improvement of a specific handoff protocol, and how the same technology could be leveraged for operational use.

Keywords: Mixed reality · Handoff training · Combat casualty care

1 Introduction and Background

Problems with the transfer of a patient's care from one medical or non-medical individual, team, aircrew, or unit to another, referred to as a "handoff," can pose significant risks to patient safety. Patient handoffs, in particular under stressful situations, are error prone and have been shown to be frequently insufficient [5,22], leading to a national imperative to improve handoff training and practice. In particular, providing care to those wounded in combat from the point of injury through the continuum of care is a challenging process that requires a coordinated effort [1,2,14]. Hence, multiple agencies seek to improve and standardize handoff training and protocols.

At the narrowest scope, a handoff consists of three core roles:

- *Giver (G)*: The person who has had custody of the *patient* and needs to convey medically relevant information about the patient to the *receiver*.

J. Y. C. Chen and G. Fragomeni (Eds.): HCII 2021, LNCS 12770, pp. 695–711, 2021.
https://doi.org/10.1007/978-3-030-77599-5_47

- *Receiver (R)*: The person who is now assuming custody of the *patient* and needs to gather medically relevant information about the patient from the *giver*.

- *Patient (P)*: The injured person being transferred from the *giver* to the *receiver*.

In practice or during training, as we widen the scope we can include additional roles as well as important aspects of the context in which the handoff is being conducted:

- *Instructor (I)*: An expert who might be guiding, evaluating, or manipulating various aspects of the handoff within a training situation.

- *Observer (O)*: A person who, during a training or evaluation scenario, passively watches the handoff for the purposes of learning or reinforcing protocol knowledge or to evaluate the effectiveness or correctness of the handoff.

- *Companion (C)*: A non-medical, non-injured participant assisting with, providing knowledge about, providing support for, or otherwise comforting the *patient*; for example, in the case where the *patient* is a wounded warfighter, this could be another warfighter from the same unit, e.g., someone who has first-hand knowledge about the mechanism of the injury, the injury itself, symptoms of the injury, and any treatment thus far.

- *Environment (E)*: This broadly encompasses a wide range of contextually relevant aspects surrounding the handoff, from peripheral entities (e.g., people or vehicles nearby) to physical aspects of the location (e.g., terrain, climate, weather, etc.) to multi-sensory events or distractions taking place in the vicinity around the handoff (e.g., explosions, shouting, gunfire, or sirens).

For many of the above roles, there could also be multiple individuals occupying the same role during a handoff, such as handing off multiple patients (P_1 through P_n), having a group of passive observers (O_1 through O_n), etc. Additionally, in practice it is common for a patient to go through multiple handoffs in sequence, with altered parameters (physiological state, applied treatments, etc.) at each handoff event. Figure 1 illustrates the core roles and additional roles involved in a sequence of handoffs.

For handoffs between a *giver* and a *receiver*, a widely used verbal report format in the military is the *MIST report*. It is designed to present the most important information rapidly. The MIST report includes the following components:

- *Mechanism (M)*: a short description of the injury mechanism, e.g., gunshot wound or fire.
- *Injuries (I)*: a list of injuries, e.g., gunshot wound to the leg (often combined with M).

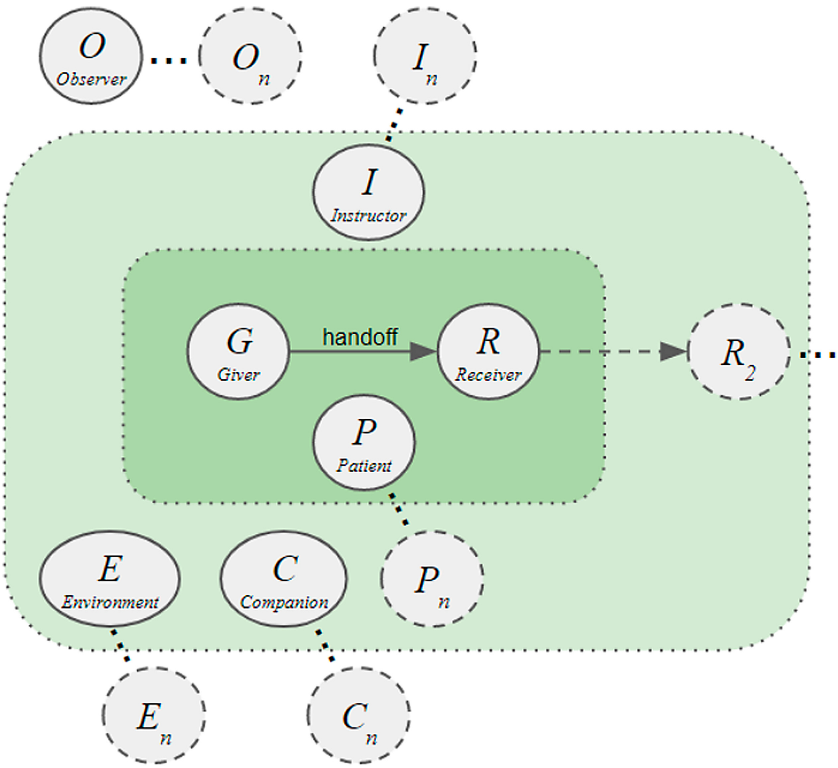


Fig. 1. Illustration of the roles involved in a handoff, including the core roles of a giver, a receiver, and a patient, which might occur in a sequence, plus additional roles of one or more instructors, observers, companions, and environmental aspects.

- *Signs/Symptoms (S)*: a description of signs or symptoms, e.g., related to the respiratory rate.
- *Treatment (T)*: a description of treatments performed on the patient, e.g., tourniquet.

There are many aspects related to the details and context of a specific handoff scenario that are independent of whether it is a real handoff or part of a training system. For example, the details of a handoff can directly cause or increase stress or cognitive load in different ways for various roles [8,12,27]. This is of particular interest in how it impacts the effectiveness or difficulty of the handoff itself as well as adhering to the desired protocol for the core roles of the *giver* and the *receiver*.

Stressors may include things such as (i) time constraints, e.g., because there is external pressure to move the patient quickly, (ii) emotional pressure from a present *companion*, or (iii) deteriorating patient physiology. In addition to general stress, a handoff participant may need to operate under increased cognitive load as a result of extraneous events or distractions or because they need to be performing additional tasks while the handoff is occurring such as watching the surroundings or listening for radio transmissions. There is further emotional load associated with the direct presence of a potentially seriously wounded patient, looking to participants for reassurance, screaming in pain, etc. While mixed reality technology generally cannot yet achieve the same levels of realism as live training, related work has shown virtual simulations do not necessarily result in reduced cognitive measures, such as mental workload [19].

In addition to the above, there are also several considerations specifically related to handoff training or the types of information or skills acquired through a specific instance of a handoff training system. Here, we focus on both practice and assessment *of the handoff and associated protocol* rather than effective learning of the handoff protocol itself. At a core level, handoff training is designed to reinforce or evaluate participants' abilities to convey the necessary pieces of information as established by the handoff protocol. While such training may be important in isolation, independent of context, aspects of the training system can also be augmented to potentially increase the overall effectiveness, especially with respect to eventually carrying knowledge over to real handoff situations.

This may involve increasing the realism of the training system by conveying contextual details relevant to the stress or mental load as discussed above, through multi-modal sensory channels, such as increasing the fidelity of the visual, auditory, or tactile representation of the environment in which the handoff is taking place. In addition to making a more immersive training environment, the details of the handoff scenario can also be manipulated to achieve handoff contexts that are more realistic, more complex, and better represent actual handoff situations a trainee is likely to encounter in practice. For example, a handoff scenario could be designed to practice triage or prioritization in a case where there are multiple patients to handoff with varying physiological states, or could evaluate the effectiveness of adhering to the handoff protocol when one or more of the participants has less or no experience with the protocol.

The remainder of this paper is structured as following. In Sect. 2, we discuss simulation asset technologies that can augment handoff complexities in a controlled manner. Section 3 discusses sensing of and feedback to trainees and instructors during handoff training. Section 4 focuses on use cases, linking training goals to infrastructures. Section 5, covers future human-subject user study design considerations, including aspects of handoff training, evaluation or improvement of a specific handoff protocol, and how the same technology could be leveraged for operational use. Section 6 concludes the paper.

2 Simulation Asset Technology

There is a variety of possible technology with which to augment a handoff training system by supporting aspects of a simulated scenario context around the handoff itself. This includes many controllable aspects of the complexities of real handoffs.

2.1 Human Roles

Humans are an essential part of any handoff training, across the variety of roles described in Sect. 1, as a *giver*, a *receiver*, the *patient*, an *instructor*, an *observer*, or a *companion* to the patient. These human roles can be realized in a number of ways, depending on the availability of real people, specifics of any included medical training tasks, and the degree to which the parameters of the training objectives or scenario details should be controlled.

For example, a single user needing to train as both the giver and the receiver requires at least some manifestation for the opposite role, and potentially a patient being handed off. This manifestation could be as simple as an invisible proxy (e.g., handing off to a non-existent receiver), or a description (e.g., textual information about a patient), or could employ other real humans, such as another trainee (e.g., two trainees practicing handing off to each other with alternating roles $\mathrm{G}_{i+1} = \mathrm{R}_i$ and $\mathrm{G}_i = \mathrm{R}_i + 1$ for training trials $i = 1, .., n$) or a role player (e.g., a standardized patient actor or an instructor playing the role of the giver or the receiver).

While real humans can be very effective at capturing realistic behavior and evoking strong emotional load (e.g., as a patient role player or distressed companion), real humans also have several limitations. Perhaps most notably, real humans may not always be available; it is advantageous for a user to have the ability to train without needing any other people physically present. Additionally, real humans are limited when it comes to accurately conveying physical wounds or physiological symptoms or state. For this reason, moulage or mannequins are already frequently used. Another possible intermediate solution is the use of virtualized humans to replace one or more of the roles. Virtual participants in a handoff could be realized as anything from basic text or rendered imagery shown on a mobile phone or tablet all the way to an augmented reality lifesize three-dimensional manifestation that can interact with the trainee and the environment [6,7,9].

Such computer-controlled virtual participants can be realized with manipulable characteristics–verbal and non-verbal–some of which are directly implicit in the handoff interaction itself while others may only be indirectly relevant. The most obvious parameters are related to what the virtual character explicitly says, either verbally or via text. For example, specific vocabulary, phrases, or grammatical proficiency may be representative or expected in a given handoff scenario. Likewise, *which information* is given or requested and *the accuracy* of the information can be controlled and may directly affect the efficacy of the handoff. Other verbal cues may have a less direct effect on the protocol procedure, such as the volume, inflection, or rate of speech, all of which may make it harder or easier to understand the other person or correctly pick out necessary pieces of information. There are also many non-verbal characteristics of a given virtual participant. In particular, if the virtual character has a visual representation, his or her expression, attentiveness, and body language can all be manipulated. Likewise, passive aspects of the participant's appearance can also be altered, such as attire (e.g., wearing a specific military uniform or civilian clothing, etc.) or cleanliness that might provide indications for the mental and physical state or capabilities of the participant in cases where the scenario is not known a priori by the trainee. Such computer-controlled virtual participants have the potential to be shared as handoff training assets among trainers and trainees and improve the overall consistency and quality among handoff training instances together with opportunities in standardization or customization.

For example, the Virtual People Factory (VPF) is a widely used tool to create interactive virtual patients for medical education [16,23]. The VPF platform of the Virtual Patients Group (VPG, a consortium of North-American universities) was developed with support by the National Science Foundation and allows developers to create interactive scenarios between real trainees and virtual patients, relying on natural language interaction. The system implements on an interaction modeling approach called *human-centered distributed conversational modeling*, in which an interaction between end-users and virtual patients generates new verbal input such as questions or statements that are then evaluated by subject-matter experts to create new appropriate virtual patient responses [15].

An important aspect of actual handoffs is that the physiological condition of the patient is dynamic before, during, and after the handoff itself. This is, of course, part of the time pressure associated with the handoff. The more visceral the concern for patient safety, the more realistic the role of such stressors in the trainee experience. A simulated patient used for handoff training could be an advanced physical mannequin or a virtual representation [24]. In either case, the medically relevant state of the patient could be controlled using complex physiological simulation software, such as Pulse or BioGears [11]. Such simulations can dynamically adapt to external conditions, react to provided treatments, or allow for specific medical events (e.g., loss of consciousness, seizure, cardiac event, etc.) to be triggered at any specific point during a handoff. Such events could be planned in order to assess how a trainee or protocol handles rapidly shifting situational parameters or priorities, or be direct results of failures during one or more handoff (e.g., as a result of treatment or lack of treatment due to incorrect or missing information).

Such interactions with virtual participants could be automated and predefined or initiated *ad hoc* by an instructor. The instructor could be co-located with the trainee or be present remotely. For instance, the TeachLivE (TLE) system for education and training has a long history of relying on remote *telepresent* operators, who can embody one or multiple virtual participants during training sessions by observing the trainees via a live video stream [21]. In this approach, the expert instructors/operators can quickly switch from one training session to the next without the need for physical relocation. This provides a vista for the scalability of handoff training with respect to automated virtual participant behaviors and human instructors/operators.

2.2 Environment and Location

In addition to having control over any virtual participants and the physiological state of one or more patients involved in a specific handoff scenario, a training system could be expanded to also have control over aspects of the environment or the context within which the handoff is taking place. This can include affecting the perceived location. For example, a handoff performed on a battlefield under active gunfire has very different immediate concerns and priorities as compared to a similar handoff done on the deck of a ship or in a field tent, and none of those locations may match the conditions in which the training takes place. Associated with different locations are many possible contextual events, such as gunfire, sirens, other virtual humans (shouting, in pain, moving around, engaging in combat, etc.), or the proximity of vehicles or aircraft. To create a sense of being in varied rich environments, hardware devices can be utilized across a range of sensory modalities. Visually, the environmental context could use a visual augmented reality head-worn display (e.g., Microsoft HoloLens or Magic Leap One), projected imagery (e.g., CAVE immersive projection technologies), or a combination of the two. There are trade-offs between system cost, portability, configurability, and scalability between different possible realizations providing the visual display. Likewise, audio could come in the form of noise-cancelling headphones (in the case where one wants to more tightly control what the trainee can hear or if training in an inherently noisy area), open-ear headphone solutions such as bone conduction headphones (if multiple users may also need to communicate with each other), or from speakers positioned in the space around the user. Vibrotactile devices, e.g., a large low-frequency transducer attached to a simple platform on which the handoff takes place, can provide haptic sensations that correspond to environmental events such as a vehicle driving by or an explosion nearby [9,10]. Smaller haptic devices, potentially as simple as a vibrating mobile phone, could be worn or carried by a user. Olfactory scent delivery systems (e.g., MENA ScentPOP) can provide contextually relevant smells, e.g., gunpowder or burnt flesh, at a very low temporal resolution during a handoff interaction.

3 Sensing and Feedback

Automating analysis or evaluation of trainees during handoff training has the potential to provide feedback to trainees and instructors that is both more specific and immediate. Perhaps the most intuitive and general purpose interface for automated analysis during a handoff is parsing verbal statements made by one or more users [20]. This can be accomplished with minimal sensor requirements—essentially just a microphone. Such core functionality lends itself particularly well as a baseline that can then be augmented, scaled up, or specifically tailored to achieve training configurations able to support handoff scenarios that are more complex and realistic, depending on the available training environment and infrastructure as discussed in Sect. 2.

For extended trainee assessment, sensors for non-verbal metrics can be employed together with the verbal analysis system, such as head-worn eye trackers for gaze direction measurements (e.g., to measure eye contact [4] or mutual gaze [18]) or sensors that capture the trainee's body language (e.g., posture or gestures [26]). Capturing such non-verbal information could be as simple as placing a Microsoft Kinect sensor nearby or as rich as having a fully calibrated, multi-camera professional motion capture setup with body-worn tracked optical markers, depending on the training needs and available hardware. Additional physiological sensors such as the Empatica E4 wristband could provide additional feedback (e.g., stress levels) on the trainee's heart rate, temperature, and skin conductance.

In addition to providing a means for an instructor to control the context and details of a specific handoff scenario prior to and during a training session, a handoff training system may also provide an interface with distilled or visualized results from any automatic analysis that occurs from the training session. For instance, this could include seeing the fields in the MIST report filled in automatically from the verbal handoff speech, along with each corresponding audio clip, and a summary of detected key words or phrases. Such an instructor interface is useful *during* a training session (for flagging events, noticing possible trainee issues, and guiding dynamic adjustments to the simulation) and also *after* the training as part of an after-action review and feedback session between the instructor and the trainee.

Likewise, automated analysis can also be used as feedback to artificial intelligence systems designed to adapt the handoff simulation to user behavior and responses both in *real-time* (e.g., a virtual human "noticing" that a user appears to not be paying attention), and *collectively over time* to adjust simulation responses and events based on collective actual trainee behaviors accumulated over many training sessions.

4 Training Use Cases

For a given training instance, there is a bidirectional relationship between the *training goals* (i.e., what is important to learn or practice) and the *training infrastructure* (i.e., the available or required equipment, people, space, etc. able to be used for the training task). For example, if the most important training goal is to reinforce a single user's ability to verbally convey certain key pieces of information during a handoff, the corresponding required training infrastructure might consist of a single tablet-based application capable of automatically evaluating one side of a handoff procedure in whatever physical setting happens to be available for the user. A training goal of having users experience something closer to the actual chaos of a battlefield handoff under heavy stress and mental load likely requires more substantial training infrastructure, and perhaps even a dedicated installation. Similarly, the available infrastructure imposes certain restrictions on the possible types of handoff and training considerations that can be introduced as part of a training session. A small group of trainees in the field may not have access to a full projector-based muti-user immersive simulated environment, but may still be able to achieve some amount of additional simulation realism through a self-contained augmented or virtual reality head-worn display in combination with smartphones or tablets to provide information and record verbal communication, with comparable benefits to training efficacy [13]. A single user at home may only have access to his or her smartphone or tablet and therefore could not learn or practice training goals requiring an immersive handoff environment, although augmented and mixed reality is expected to continue becoming more prevalent, even in such situations [25].

The following three example use cases span a range of possible manipulable handoff and training considerations. These examples correspond to a baseline of relatively minimal technological capabilities, the Uniformed Services University of the Health Services (USUHS), and the simulation infrastructure at the Synthetic Reality Lab (SREAL) at the University of Central Florida (UCF).

1. *Asynchronous training* – Like the notion of asynchronous learning, *asynchronous training* is a trainee-centered approach to training, performance enhancement, and assessment without the constraints on time, place, and people. In the most basic manifestation, one or two trainees could, for example, utilize smartphones or tablets with speech recognition capabilities at a convenient location and time. By supporting ad hoc use that relies on a minimal set of relatively small, low-cost devices, this configuration has a few strong advantages: (i) it is likely that the necessary hardware is either already on hand or is easily attainable, (ii) the setup likely does not require an expert and initiating the training could be as simple as running an app on each device, and (iii) any convenient and available location can be used, as long as it meets some threshold for ambient noise that might interfere with automated voice recognition. On the other hand, this manifestation alone *cannot* capture fully realistic handoff factors such as environmental distractions, patient physiology, other roles, etc.
2. *Highly immersive training* – Towards the other end of the spectrum are specialized immersive training facilities. An example is the WAVE at USUHS [3], which supports large-scale combat casualty care training in an 8,000-square-foot area composed of two pods surrounded by circumferential 9 12-foot movie screens and a directional sound system (see the bottom-left insert in Fig. 2). Such a training setup can support group training with immersive environmental aspects (e.g., three-dimensional visual stimuli and spatial audio), using live standardized patients or advanced medical mannequins. Such facilities are very effective at providing a realistic context for a set of specific scenarios. However, they require some instrumentation of users (e.g., shutter glasses or immersive virtual reality head-mounted displays), require a substantial amount of dedicated space, and are very expensive and complex to setup and operate.
3. *Outdoor field training* – Instead of immersing users in a virtual training environment, portable augmented reality technologies such as head-worn displays and haptic feedback platforms, e.g., employed in our related outdoor training

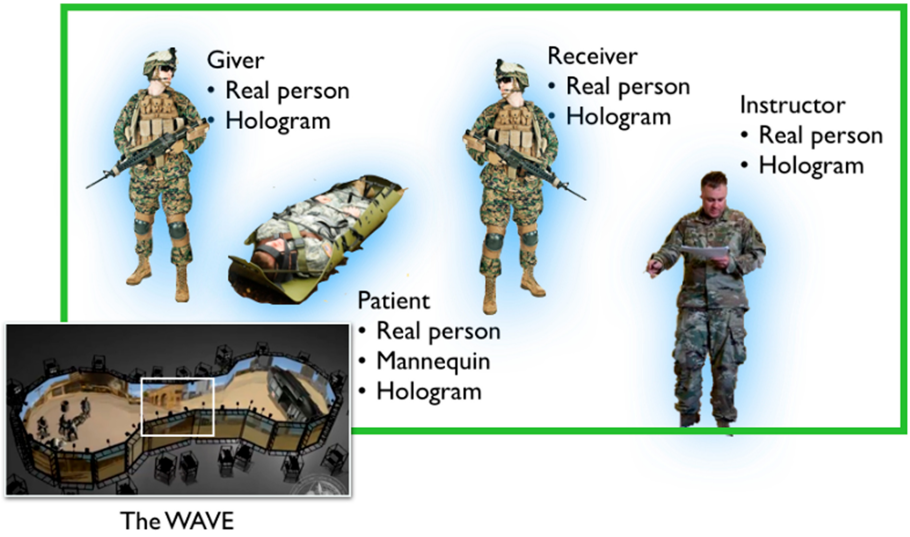


Fig. 2. Illustration of handoffs with different roles enabled by the technologies available in USUHS' highly immersive WAVE training facility, which features surrounding projected virtual imagery and audio feedback.

research, are able to embed virtual stimuli in the real environment, which is particularly effective if trainees are in a meaningful physical location such as on a field exercise. Such devices are significantly less expensive than a fully dedicated immersive simulation facility, and can support training in a variety of available locations, leveraging aspects of the existing physical environment where possible (e.g., making use of physical terrain, buildings, weather conditions, etc.). The use of augmented reality displays allows for any number of human roles to be occupied by real entities (e.g., live standardized patients, physical mannequins, or other human trainees) or highly controllable 3D virtual humans, depending on training goals. Although flexible, there are limitations on the spatial extent of a haptic platform (e.g., see Fig. 3) and users are required to wear head-worn displays that with current technology have a limited field of view for displaying virtual content.

Although the example use cases here are described largely as pertaining to training related applications, similar infrastructure could additionally or simultaneously allow for the possibility of testing a handoff *protocol* as well. For example, the same automated analysis technology discussed in Sect. 3 could be used to assess the robustness of the protocol itself rather than the user by identifying which specific aspects of the protocol break down under specific simulated contexts (e.g., in the presence of distractions, noise, or other more realistic conditions).

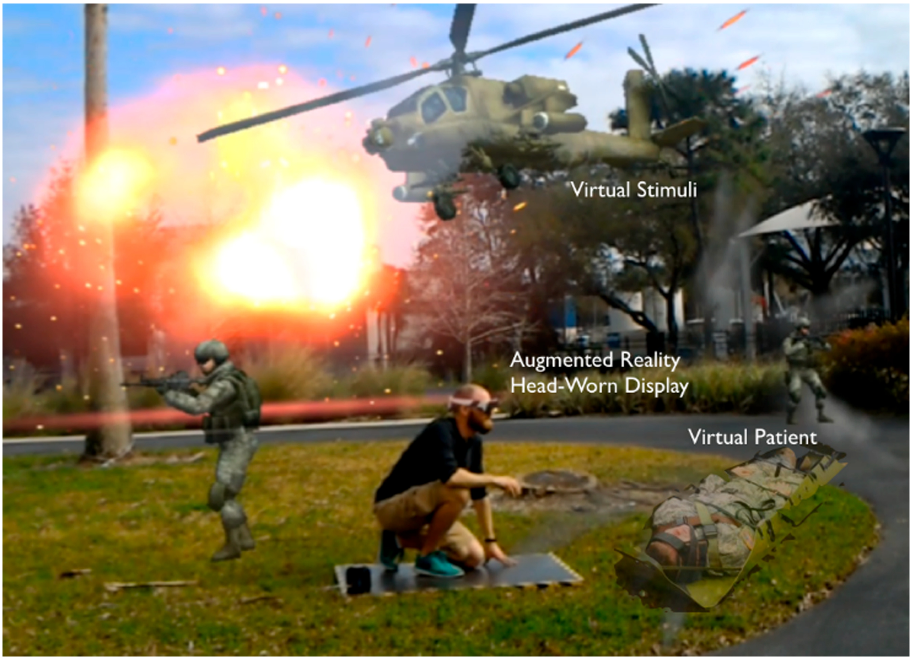
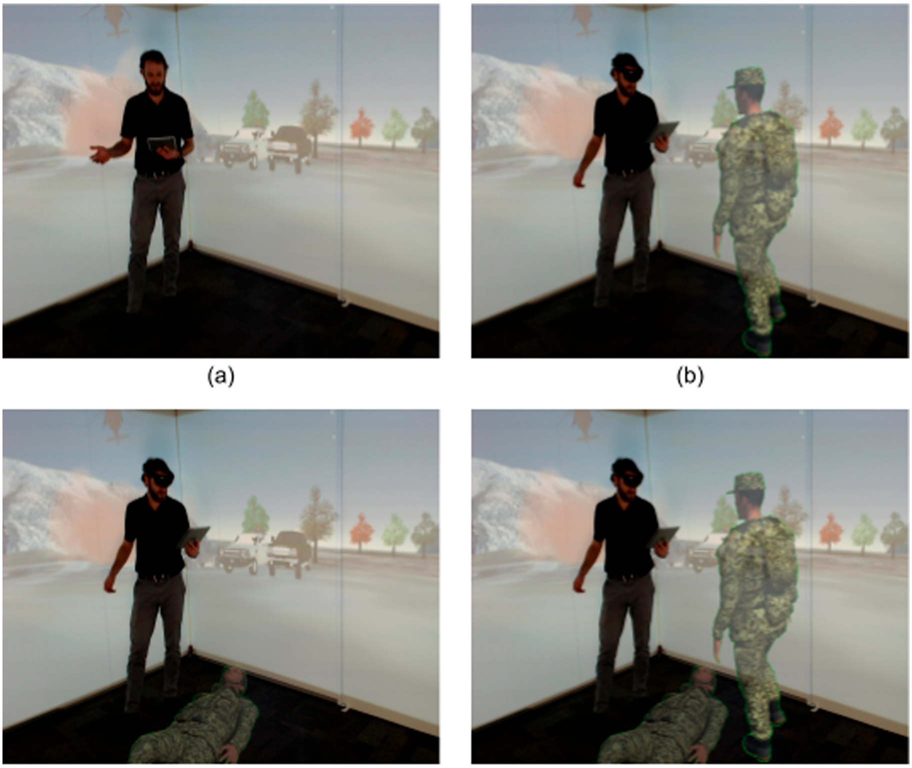


Fig. 3. Illustration of outdoor field training as researched at UCF, involving the use of augmented reality head-worn displays and visual stimuli involving virtual handoff participants as well as environmental effects.

5 Study Design and Evaluation Discussion

In light of the extensive range of possible manipulable aspects both explicit and implicit to handoffs in a training setting, we see a significant opportunity for evaluating the strengths and effectiveness of *specific* capabilities through human-subject user studies. The current COVID-19 pandemic presents a variety of challenges making in-person studies significantly more difficult logistically. In particular, even in addressing device disinfection, contact and proximity-limiting procedures, and more stringent Institutional Review Board (IRB) requirements, such user studies during pandemic conditions would likely have an additional psychological effect on participants. Participants may be (consciously or subconsciously) aware or concerned about personal safety with respect to being in shared, enclosed spaces, having extended physical contact with headsets or other equipment that could be perceived as potentially contaminated, adding additional confounds to any collected data or results.

In anticipation of being able to resume more normal human-subject studies, here we discuss some study design considerations. For example, SREAL's Human Surrogate Interaction Space (HuSIS) [17] provides a highly instrumented space for *simulating* a variety of field contexts within a much more controlled environment. Such an experiment testbed can allow for stable and predictable evaluation



(a) (b) (c) (d)

Fig. 4. Illustration of four mixed reality handoff training environments at UCF, showing different configurations of head-worn and projection-based displays, textual or full-body real or virtual representations of handoff participants and patients.

between technological realization or other factors of handoff training. For example, Fig. 4 shows an illustration of four potential study conditions comparing the manifestation (not present, textual only, or virtually present via an augmented reality headset) of both a *receiver* and/or a single *patient* within a hypothetical remote handoff location, with environmental context provided via the projection walls of the HuSIS, along with other multimodal stimuli, such as spatial background audio or haptic effects such as wind from a nearby helicopter.

Additionally, we discuss some interesting evaluation areas that may be initially less intuitive, such as the use of a handoff training system for improving the *protocol* itself, the *learning* of the protocol, and possible *operational use* opportunities that could also further guide and/or improve the training aspects.

5.1 Evaluation of Protocol/Education

Training use cases 1–3 in Sect. 4 are aimed at training individuals who have been educated in some way to use a particular protocol (e.g., MIST) in various handoff circumstances. However the same system technology could be used to evaluate the effectiveness of the protocol itself, or the educational process and tools used to learn the protocol.

For example, a particular protocol might be more or less able to accommodate secondary information from a companion (e.g., a fellow Soldier or Marine), might be more/less robust to language mismatches or spoken accents, more/less robust to time pressures, more/less robust to environmental distractions, and more/less robust to participant distractions. Also, a particular learning module or educational step might be more or less effective than another, or some variation.

The exact same technology used for training and assessing individuals could be used to assess *protocols* by holding the participant handoff skills constant, varying the participant or environment conditions, and measuring the effectiveness of the handoff. Protocol sensitivity analysis could be carried out much the same way sensitivity analysis is carried out for other systems: by choosing one parameter of interest, e.g., a particular wording or step of the protocol, then holding all other parameters constant while carrying out handoff instances and measuring the effectiveness of the handoff in the presence of small perturbations of the parameter of interest. This sort of differential analysis can provide insights into the fragility/robustness of the protocol. Whole new protocols or variations of protocols could be assessed in this way.

Similarly, the exact same technology used for training and assessing individuals could be used to assess *the process and tools used to learn* the protocols, by holding constant the participant handoff skills and the environment conditions for example, then varying the educational process or tools, and measuring the effectiveness of the handoff. Education sensitivity analysis could be carried out much the same way as protocol sensitivity analysis described above. Again, this sort of differential analysis can provide insights into the fragility/robustness of the education process or tools, and whole new educational modules or tools could be assessed in this way.

5.2 Evaluation of Operational Use

As depicted in Fig. 5 we recognize and envision that many of the technologies and insights discussed have promising potential for operational use as well. Real-time feedback provided to an instructor, such as automatically parsed and populated fields corresponding to MIST could instead be used as part of an operational system where an actual user could, for example, be given a visual indication of the automatically parsed speech, or detected type of information, serving as a passive checklist or reassurance to a user that nothing is erroneously omitted during an actual handoff. Taking it a step further, a system could provide active visual or auditory prompts for pieces of information that may have been skipped or that require clarification. Additionally, an operational use system could help with remembering specific details of what happened or what treatment steps have already been taken, potentially allowing the giver to provide a more accurate and detailed account during a subsequent handoff. Such visual and auditory feedback

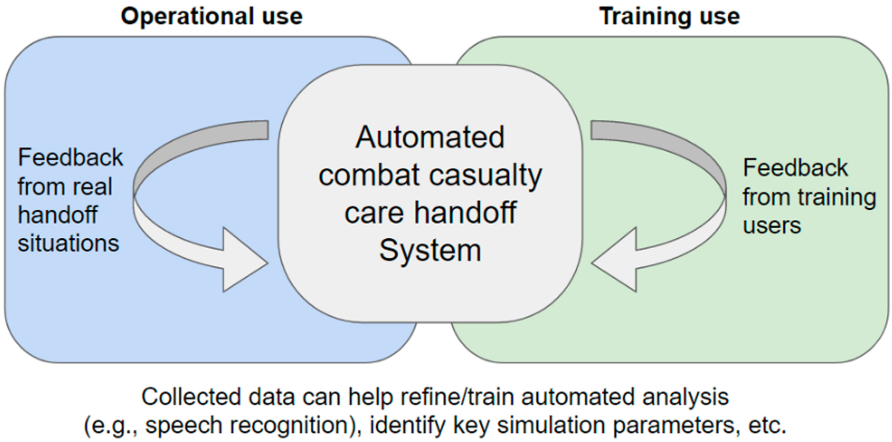


Fig. 5. Illustration of feedback mechanisms from operational or training use.

could be presented via something as simple as the user's existing communication radio output, or as complex as an integrated mixed reality display.

The inclusion of automated analysis in an operational context enables several novel possibilities related to the tracking and flow of data and information related to a patient, accumulated across a series of multiple handoffs of the same patient. This data could include patient physiology, both current state and accumulated history, verbal information as provided by the *patient*, previous *givers*, or a *companion* (e.g., accounts of what happened), as well as any treatments provided along the way. Such data could automatically transfer from person to person, associated with the patient, and provide a clearer and more complete timeline of events while detecting or reducing the risk of erroneous information or misunderstandings across multiple handoffs.

As with data collected during training, operational data could be aggregated across handoffs to bootstrap and adapt the system to be more effective both in continued operational use but also to provide more accurate training scenarios or to emphasize training related to aspects of the handoff that frequently cause the most critical issues in actual handoffs (see Fig. 5).

Operational data, including physiological measures, voice notes, etc. could be cached with/on a data device affixed to the patient, and uploaded to the cloud as the patient comes into range (edge) of the cloud, e.g., at a field hospital where Wi-Fi is available. Conversely, patient-specific cloud data could be downloaded to the patient device so that it is available off-line (when away from the cloud). Each access (input or output) would be logged with the ID of the individual, thus maintaining a complete chain of communication both for historical records and for operational needs, e.g., if more information is needed from one individual somewhere in the chain of handoffs. Synchronizing patient data between the cloud and the patient this way would provide the most reliable, timely, and useful access to the data, and the place and time where it is needed.

If the operational data is cached with/on a data device affixed to the patient as described above, and synchronized to the cloud when possible, this could help support *asynchronous handoff*. For example, if someone with knowledge about the mechanism of injury is able to convey information before the receiver is available, that information could be conveyed and then held until the appropriate receiver is available to receive it.

Finally, if asynchronous handoff is supported as described above, handoff involving future *robotic warfighter rescue devices* would be naturally supported. Warfighters at the point of access could provide information and immediately get back to the fight, while the wounded warrior and the critical handoff information is transported to an appropriate safe space. Mixed reality representations of a *receiver* (in the case of a warfighter asynchonously handing off "to" a robotic device) or *giver* (in the case of the person asynchronously receiving the casualty) could further assist in capturing and reproducing more natural handoff interactions, potentially increasing effectiveness or reducing errors.

6 Conclusion

In this paper we described technologies and use cases for combat-casualty handoff training with a view on the different roles involved in a handoff and related simulation asset technologies. We discussed a range of technological realizations for handoff training, with an emphasis on the significant benefits of integrating mixed reality capabilities for embodied three-dimensional virtual roles with the handoff context. Finally, we present some considerations for future human-subject studies to explore and evaluate many of the mixed reality handoff training combinations and parameters, including two closely related ideas of handoff protocol evaluation and how the same or similar technology could additionally be leveraged for or in combination with operational use situations.

Acknowledgment. This work is supported by the Defense Health Agency as part of the Defense Health Program under Contract No. W81XWH-19-C-0023; and the AdventHealth Endowed Chair in Healthcare Simulation (Prof. Welch). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the official views of the U.S. Government or Department of Defense.

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